

The Mariner 9 Quasar Experiment: Part I

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Differential very long baseline interferometry (VLBI) experiments were conducted in 1972 between Mariner 9 and various quasars. The objective of these experiments was to determine the position of Mars in the VLBI reference frame. This first of two articles gives background and describes experimental procedures. A subsequent article will describe the analysis of the data and the result obtained for the differential position.

I. Introduction

The technique of very long baseline interferometry, presently under rapid development, holds promise of making important contributions to spacecraft navigation. Through VLBI observations of extragalactic radio sources, many of them quasars, it will be possible to determine Earth's orientation (UT1 and polar motion) accurately with respect to the inertial frame formed by these sources. Our expectation is that within the next 5 years VLBI will be able to provide, for example, measurements of UT1 routinely with uncertainty below the 1-ms level, which

projects to a position error of about 10 km at a geocentric distance of 1 AU (still by no means the theoretical limit of the technology). In order to utilize this accuracy for interplanetary spacecraft navigation, we must know the orientation of the planetary system with respect to the same inertial frame. Since the planets are not themselves suitable targets for VLBI observations, an indirect approach is necessary. It was therefore suggested by one of us (I.I.S.) that a spacecraft in orbit about another planet would be an appropriate target.

In brief, the procedure proposed was to utilize two of the DSN antennas to observe alternately, but in synchronism, the spacecraft and an extragalactic radio source that lies nearby in the sky. With sufficiently stable frequency standards and adequate signal-to-noise ratios, it is possible to switch back and forth between observations of the spacecraft and the natural radio source so as to be able to determine the time development of the fringe phase for each target without the introduction of any 2π ambiguities other than the initial one that affects all such observations. The differences in the fringe phases for the two targets represent extremely accurate observables since they are freed, through cancellation, from most instrumental effects. Because the two sources, by design, subtend a very small angle at Earth, the propagation-medium effects tend to cancel as well. This technique of differential VLBI (Δ VLBI) appears capable, when developed, of the determination of relative positions with an uncertainty at the milliarcsecond level. (Also see Ref. 1.)

The first opportunity to apply this technique arose with the Mariner 9 spacecraft in January 1972. During this primary portion of the mission, several sets of observations were conducted. Other observations were carried out during the extended mission. Unfortunately, the required first local oscillator (LO) signal could not be derived from the station frequency standards by integer multiplication because of the lack of appropriate instrumentation. Therefore, the first LO chain was driven by a synthesizer signal and, as a consequence, sufficient frequency stability with the interferometer was not obtained to allow the fringe phase to be "connected" between observations of either of the two targets without the introduction of 2π ambiguities.¹ Therefore, only the fringe rates, which are inherently unambiguous although less accurate, were available for the determination of relative position. A detailed description of these experiments is given in the following sections; the results will be discussed in the final article of this two-part series.

II. Experiment Description

Initially, three sets of observations were taken on January 17, 20, and 25, 1972, during mutual visibility between the 64-m Mars antenna (DSS 14) at Goldstone, California, and a 26-m antenna at Woomera, Australia (DSS 41). The natural source which was observed alternately

with Mariner 9 was the quasar P0106 + 01. Later in the year, another set of observations was made during the extended mission on October 13 and 17. On a third day (October 27), observations could not be carried out because of the final loss of altitude control gas by Mariner 9. This later series of observations was carried out between the 26-m Echo antenna at Goldstone (DSS 12) and DSS 41, with the natural sources observed being the quasars 3C273 and 3C279.

Unfortunately, no observations after January 20 were successful. The cause of these failures is believed to be in the frequency system of one or both stations. The observations of 3C273 yielded intermittent, weak fringes; no other signals were detected.

On each of the 2 days when useful data were obtained, three kinds of tracking were performed. Table 1 summarizes these tracking modes. During the first 2 h, the spacecraft was completing its high-bit-rate science playback to DSS 14. This signal was simultaneously recorded to be processed in a VLBI mode using the 24-kHz system (Ref. 2). Three-way doppler data were also obtained during this same interval. The next 2 h, until Mariner 9 set at DSS 14, were used for the actual switching experiment. Finally, 4 h of observations on various natural radio sources were taken at the same frequency as the switching experiment to give sensitivity to baseline and clock parameters.² On January 20, runs 9–13 of the switching experiment were lost due to an unanticipated, although mission-planned, termination of the high-rate science sub-carrier signal which served as the interferometer illuminator.

III. Data Reduction

The accuracy of the data, as explained above, did not approach the level possible for this type of experiment. However, these data did allow the development and checkout of software to be used in later experiments. Therefore, the exercise of processing these data was carried through.

The cross-correlation of the magnetic tapes was accomplished using a modification of software developed for Earth physics and UT1 observations (Ref. 3). The model for the spacecraft motion used in fringe stopping was taken from probe ephemeris tapes (PETs). The ephemeris for Mars was the JPL ephemeris designated DE69 (Ref. 4).

¹Had four antennas been available (a pair at each end of the long baseline), observations of each target could have been carried out continuously, and this lack of frequency stability would have been of no consequence (provided the same local oscillator signal was used at each antenna pair).

²The differential position measurement, however, has virtually no dependence on these parameters.

Figure 1 shows typical residual sine fringes for Mariner 9 over a small portion of one VLBI tape pair on January 17. The best-fitting sine wave over this interval is also shown.

The fringes which resulted from the cross-correlation were then analyzed to extract the information about the time development of the fringe phase (Ref. 3). Differencing the relative fringe phase at different times for a given source then yielded average fringe rates over these intervals. The results from one such analysis are shown in Fig. 2 for a tape taken on January 20. The residual phase after a constant fringe rate was removed is plotted as a function of time from the beginning of the tape. The figure also illustrates the antenna switching sequence followed in all

the switched observations. The spacecraft phase points are more finely spaced because the higher signal-to-noise ratio for Mariner 9 allowed a shorter averaging time (12.8 s compared to 57.6 s). Note that the scale of the abscissa is $\sim \frac{1}{3}$ cycle of S-band phase (~ 4 cm light-time equivalent).

The final step in the processing of the raw observations was the removal of the phase models used in fringe stopping for the two sources. The resulting "total" fringe rates were then analyzed using programs with more sophisticated modeling of the theoretical expression for the motion of Earth and the spacecraft. The result of this analysis is to be the subject of the final article of this two-part sequence.

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References

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Table 1. Tracking mode summary

Run Nos.	Time (U.T.)	Mode
1-8	0220-0420	Mariner 9 only
9-19	0427-0647	Δ VLBI
20-35	0649-1041	Natural sources only

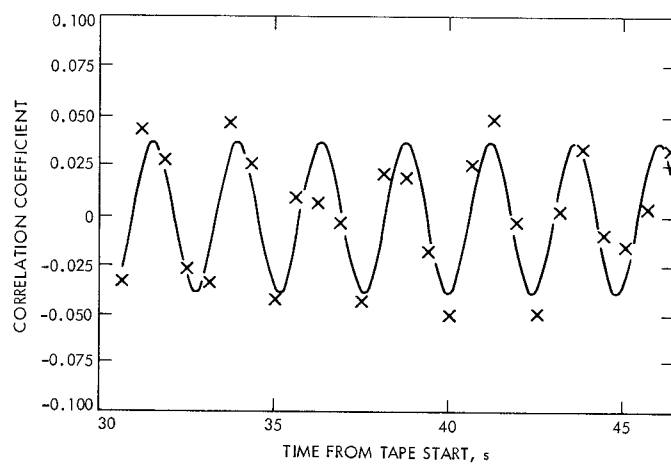


Fig. 1. Typical residual sine fringes for Mariner 9

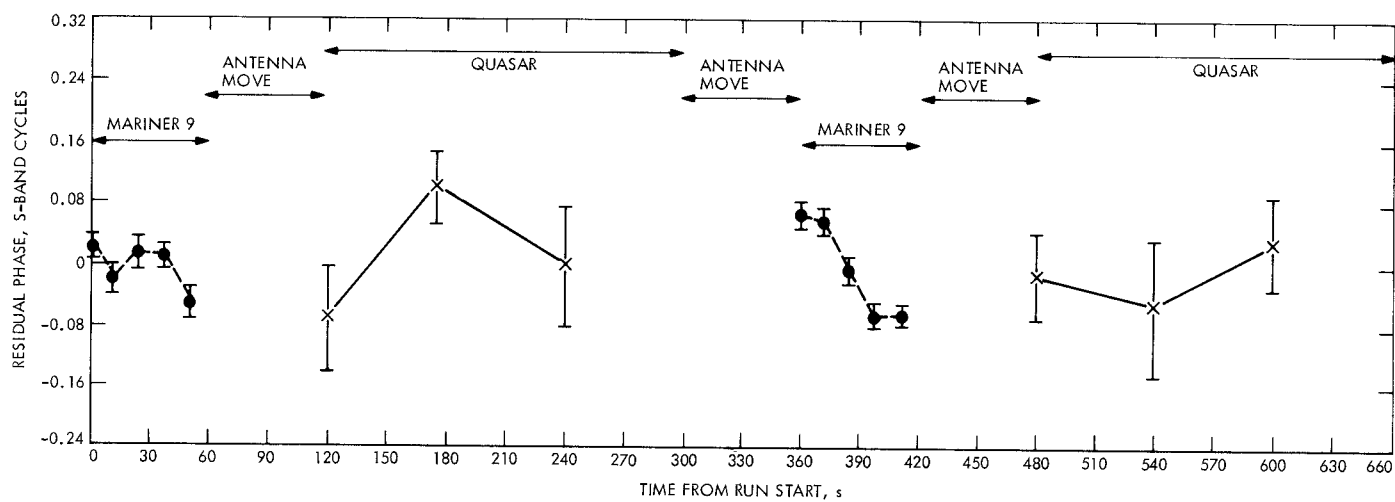


Fig. 2. Results of fringe phase analysis